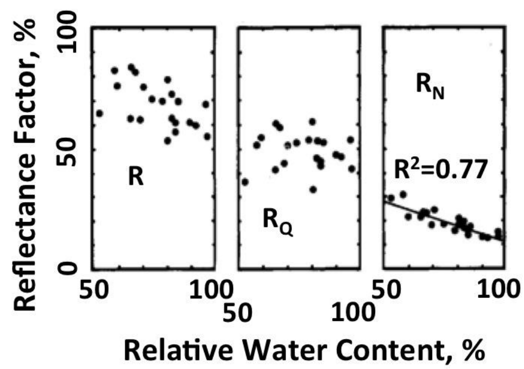
Relative Water Content, Bidirectional Reflectance and Bidirectional Transmittance of the Interior of Detached Leaves during Dry Down

Vern Vanderbilt[1], Craig Daughtry[2], Robert Dahlgren[3]

[1]NASA Ames Research Center, Moffett Field, California, USA;
[2]USDA-ARS Hydrology & Remote Sensing Lab, Beltsville, Maryland, USA;
[3]CSUMB/NASA Ames Research Center, Moffett Field, California, USA

1. INTRODUCTION



Remotely sensing the water status of plants and the water content of canopies remain long-term goals of remote sensing research [1]. Estimates of canopy water content commonly involve measurements in the 900nm – 2000nm portion of the optical spectrum [1]. We have used optical polarization techniques to remove leaf surface reflection and to demonstrate that the visible light reflected by the interior of green healthy corn leaves measured *in situ* inversely depends upon the leaf relative water content (RWC) [2].

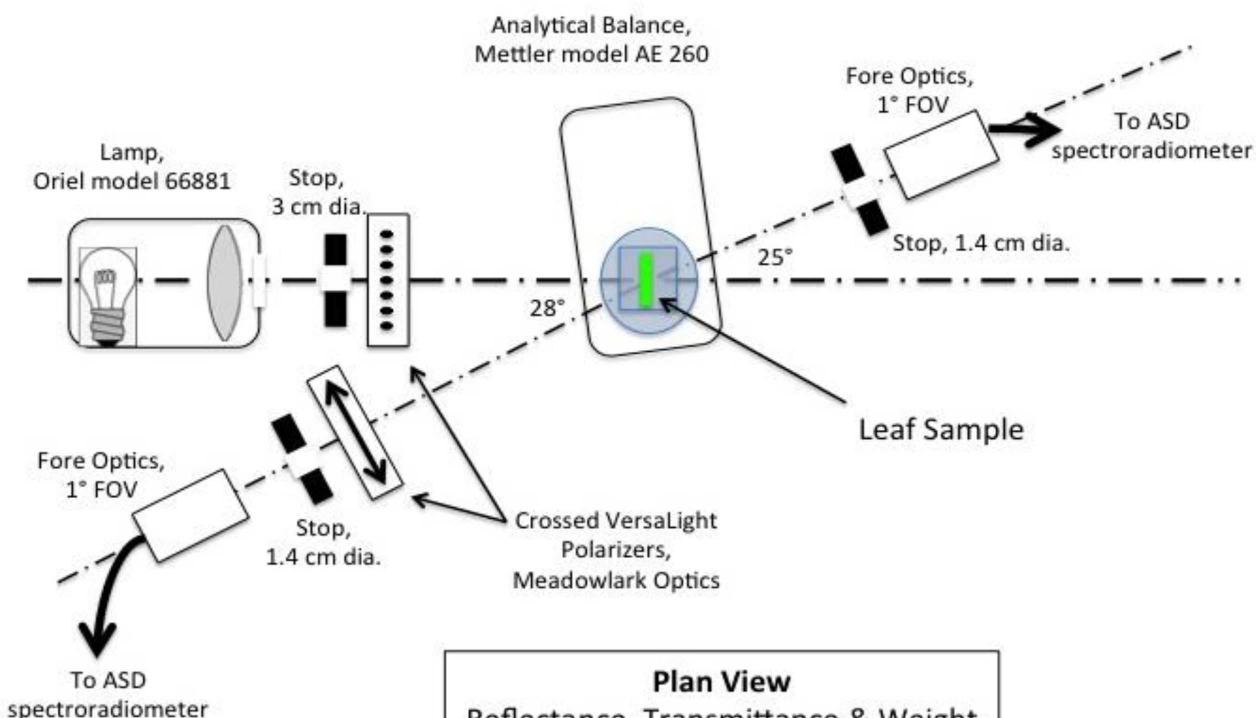
In the research reported here, we again used optical polarization techniques in order to remove the leaf surface reflection from our measurements. This allowed us to monitor the interiors of detached corn leaf samples during leaf dry down — measuring for each sample the RWC, bidirectional spectral reflectance and bidirectional spectral transmittance over the wavelength range 450nm to 2,500nm. Our new results – like our earlier results — show light scattered by the leaf interior measured in the visible wavelength region generally increased as leaf RWC decreased. However, the spectral character and the much improved signal/noise of our new results shows the RWC-linked visible light scattering changes are due to leaf structural changes. Our new results show that scattering changes that occur with changing leaf RWC are not attributable to molecular configuration changes in cellular pigments.

2. METHODS

We harvested fully expanded upper leaves of corn (Zea mays) plants in a large field in the vegetative development stage just prior to flowering, immediately placed the leaves in an ice chest partially filled with ice covered with cloth and transported the chest to the lab. We rehydrated the leaves overnight by placing the cut end of each leaf in water and enclosing the remainder of the leaf in a clear plastic bag.

The next morning in the lab we prepared to measure the leaf bidirectional reflectance and bidirectional transmittance by completing as quickly as possible the following sequence when a leaf sample was needed for measurement purposes: remove the now fully hydrated leaf from the plastic bag, blot the leaf dry, trim the leaf in order to select a 4.5 cm x 4.5 cm leaf sample, mount the leaf sample in the sample holder and, for measurement purposes, place the sample holder (with leaf sample) on the pan of the analytical balance, Mettler model AE 260.

We illuminated the leaf sample with a collimated beam of white light provided by a current controlled lamp, Oriel model 6681, and immediately began collecting spectral data and sample weights with the aid of a Mettler analytical balance and two Analytical Spectral Devices spectroradiometers. The leaf sample, initially fully hydrated at 100% RWC, rapidly began loosing water when exposed to the light.



Plan View
Reflectance, Transmittance & Weight
of Leaf Sample During Dry Down

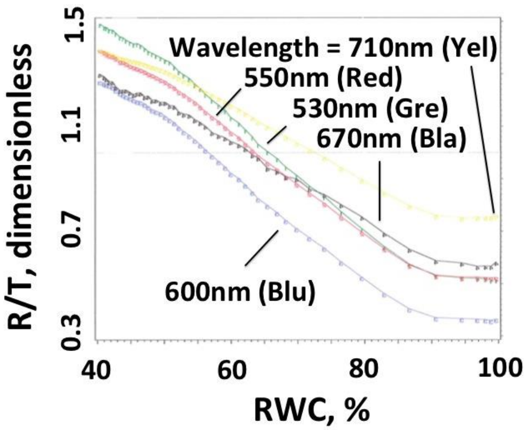
Data collection continued until we estimated the leaf sample RWC was less than 65% (approximately the permanent wilting point for corn), which turned out to be 1.5 to 2 hours.

We later dried the leaf samples in a 65 °C oven for 2 days, cooled the leaf samples and estimated RWC for a specific leaf weight as {[(fully hydrated leaf weight) – (leaf weight)]/[(fully hydrated leaf weight) – (dry leaf weight)]}.

We calibrated the spectra using a multi step procedure involving observation of Spectralon by both reflectance and transmittance spectrometers and observation of opal glass by the transmittance spectrometer. The crossed polarizers eliminated the light reflected by the leaf surface, allowing the reflectance spectrometer to observe the light reflected by the leaf interior.

3. RESULTS

Our results show that light scattered by the leaf interior measured in the visible wavelength region generally increased as leaf RWC decreased. These RWC-linked visible light scattering changes are due to leaf structural changes; that is, as RWC decreases, the cells of the leaf change structurally from what are initially fully hydrated 'plump grapes,' becoming more like 'wrinkled raisins' as the RWC approaches the permanent wilting point of the leaf. The cell surface area per unit volume is much less for the fully hydrated leaf than for the desiccated leaf, and as a consequence, as the leaf RWC decreases, the amount of light scattered by the interior of the leaf increases.



Our results (left) show that the ratio of reflectance to transmittance varies linearly with RWC when RWC is less than 85%-90%, approximately zero turgor, the point at which the internal hydrostatic pressure in the leaf cells is zero. These results reveal the R/T curves for various wavelengths are offset vertically, one compared to another, suggesting that

measurements of reflectance and transmittance at one visible wavelength might allow estimation of the RWC of water stressed corn canopies for which RWC<85%.

4. CONCLUSIONS

These results suggest that the relative water content of a plant canopy potentially may be estimated by remotely sensing the visible light scattered by the leaf interiors of the canopy. The remote sensing approach would depend upon applying optical polarization techniques [3] to plant canopy spectra in order to remove from the measurements the light reflected by the surfaces of the leaves of the canopy.

5. REFERENCES

[1] Ustin, S.L., D. Riaño and E.R. Hunt, Estimating canopy water content from spectroscopy. Israel Journal of Plant Sciences. 2012, 60:9-23.

[2] Vanderbilt, V.C., L. Grant and C.S.T. Daughtry, Polarization of light scattered by vegetation. Proceedings of the IEEE, 1985, 73:1012-1024

[3] Vanderbilt, V.C., K.J. De Venecia, Specular, diffuse and polarized imagery of an oat canopy. IEEE Transactions on Geoscience and Remote Sensing. 1988, 26:451-462.